NEW HYDROUS MAGNESIUM-BORATE MINERALS IN TURKEY: KURNAKOVITE, INDERITE, INDERBORITE

Orhan BAYSAL

Hacettepe University, Department of Earth Sciences

SUMMARY. — The largest borate deposits of Turkey were found at Sarıkaya which is located 4 km west of Kırka county of Eskişehir. Sarıkaya borate deposits formed by the deposition in the lake of Neogene, of volcanic ash, mud and exhalation products coming from the faults and containing boric acid, sodium and magnesium. Therefore the deposits are of exhalative-sedimentary origin.

The author who has studied the mineralogy and the genesis of the deposits, has witnessed the presence of several Mg-borates. These are triclinic *kurnakovite,* $Mg_2B_6O_{11}.15H_2O$, monoclinic *inderite,* $Mg2B_6O_{11}.15H_2O$, and monoclinic *inderborite,* $CaMgB_6O_{11} . 11H_2O$. All these minerals have first been observed in Turkey at Sarıkaya borate deposits. The minerals have been studied by microscopic, chemical and X-ray diffraction methods.

There is a considerable confusion in the literature of western countries about the nomenclature of hydrous Mg-borate minerals. Heinrich (1946), and Frondel and Morgan (1956a) call *kurnakovite 'inderite',* and Frondel and Morgan *(1956b)* call *inderite 'lesserite'.* It is therefore necessary that corrections should be made immediately, of these inappropriate definitions which are also listed in ASTM.

INTRODUCTION

Studies since 1968 in the field and in the laboratory have indicated the existence of a large borate deposit at Sarıkaya (Kırka county, Eskişehir) (Baysal, 1968; 1969; 1970; 1972a). The region is covered with Neogene lacustrine-volcanic facies sediments deposited in the tectonic lakes that formed mostly by vertical movements. The bottom of the deposits consists of marl-clay series and the top of clay-marl series. The borate series contain several borate minerals along with local marl, clay and tuffaceous interlayers.

These borate deposits formed in the Neogene lakes, from volcanic ash and mud, and from the boron-exhalations coming from SSW-NNE faults of early Pliocene. The deposits have been deformed by vertical movements both in the beginning and during their forming, and took their appearance of today.

In Sarıkaya borate deposits one finds beside *borax, ulexite, colemanite, tunellite, meyerhofferite, inyoite, kurnakovite, inderite* and *inderborite* which are Mg- and Mg-Ca-borate minerals. *Kurnakovite, inderite* and *inderborite* have first been found in Turkey at Sarıkaya borate deposits. Therefore in this paper only Mg- and Mg-Ca-borate minerals are taken up. Detailed mineralogical, genetic, geochemical and petrographic studies of Sarıkaya borate deposits are given in Baysal (1972a).

INAPPROPRIATE DEFINITION OF KURNAKOVITE AND INDERITE

There has been a considerable confusiort in the literature of western countries about the two hydrous magnesium-borate minerals.

According to the latest research it is established that *inderite* and *kurnakovite* are two polymorphs with the composition $2MgO.3B_2O3.\ 15H_2O$. *Inderite is* monoclinic and *kurnakovite* is triclinic (Rumanova & Ashirov, 1964; Da-Nean, 1965; Christ *et al*., 1967). *Inderite* was first discovered and reported by Boluyreva (1937) and Godlevsky (1937) and *kurnakovite* by Godlevsky (1940) in the borate deposits of West Kazakistan, Russia. In the meantime *inderite* was synthetically made and studied by Feigelson *et al.* (1939), Nikolaev and Chelishcheva (1940), D'Ans and Behrendt (1957) and *kurnakovite* was synthesized in the laboratory by Spiryagina (1949).

Heinrich (1946) asserts that he found one of these minerals in the U.S.A. He named this mineral '*inderite'* and was also able to make it synthetically in the laboratory. But it is doubtful that this mineral, which is called 'American material' is from the deposits of California, especially from Kramer (Frondel & Morgan, 19560; Schaller & Mrose, 1960).

The samples collected from two different mines in Kramer, California (Baker and Jenifer) were found by Frondel and Morgan (19560) to be identical with the mineral which was called *inderite* by Heinrich (1946). Therefore Frondel and Morgan also called their mineral *'inderite'.* Soon after, Frondel and Morgan *(1956b)* found a monoclinic dimorph of this mineral, again from Jenifer mine, and thinking that this is a new mineral called it *'lesserite',* Thus the descriptions and nomenclature of Heinrich (1946) and Frondel and Morgan (1956a, 1956b) went as such in ASTM as well as in the literature of the western countries.

The author found discrepancies when he compared the optical, chemical and diffraction properties he obtained from the Mg-borates with those in the literature. Therefore the author searched the literature in detail and found an important paper about the hydrous Mg-borates. Schaller and Mrose (1960) mention the same discrepancies. These authors worked on an original *kurnakovite* sample contributed by Prof. Dr. M.A. Valyashko, and found that the results obtained from powder diffraction analyses fit the diffraction properties *of inderite* which was analyzed by Heinrich (1946). The author has obtained the same results from the Mg-borates of Sarıkaya. Schaller and Mrose record that they studied thoroughly the samples from the deposits of Kramer (California) and that they would publish their results in the future, but no such publication has yet been made.

Thus on the one hand the results this author has obtained and on the other hand the work of Schaller and Mrose (1960) indicate clearly that the mineral defined as *inderite* by Heinrich (1946), Frondel and Morgan (1956a) and Morgan (1956b) is really *kurnakovite,* and that which is defined as *leaserite* by Frondel and Morgan *(1956b)* is *inderite.* Therefore it is urgent that the inappropriate definitions in the literature be corrected.

Table 1 is included here to prevent further complications about the definitions of *inderite* and *kurnakovite.* This table lists the data given by Schaller and Mrose (1960) and the results of this author's work.

KURNAKOVITE

Structure formula : $Mg\ [B_3O_3\ (OH)_5].5H_2O$
Oxide formula : $2MgO.\ 3B_2O_3.15H_2O$

Occurrence

Kurnakovite was first reported, as mentioned above, by Godlevsky (1940) from the Inder borate deposits in West Kazakistan and later by Frondel and Morgan (19560) from the Jenifer mine of Kramer borate deposits of California. Frondel and Morgan (19560) called this mineral *'inderite'* following Heinrich (1946) who had called *kurnakovite 'inderite'.* In Turkey *kurnakovite* was first found in the borate deposits of Sarıkaya.

Table - 1

Classification of hydrous Mg-borate minerals

Inderite : $2MgO.3B_2O_3.15H_2O$ Monoclinic	*Kurnakovite* : $2MgO.3B_2O_3.15H_2O$ Triclinic
*Natural**	*Natural**
Inderite BOLDYREVA (1937)	Kurnakovite GODLEVSKY (1940)
Inderite GODLEVSKY (1937)	'Inderite' HEINRICH (1946)
'Lesserite' FRONDEL & MORGAN (1956*b*)	'Inderite' FRONDEL & MORGAN (1956*a*)
'Lesserite' MUESSIG (1959)	'Inderite' MUESSIG & ALLEN (1957)
'Lesserite' PENNINGTON & PETCH (1962)	'Inderite' MUESSIG (1959)
Inderite PETCH *et al.* (1962)	'Inderite' PENNINGTON & PETCH (1960)
Inderite RUMANOVA & ASHIROV (1964)	Kurnakovite PETCH *et al.* (1962)
Inderite CHRIST *et al.* (1967)	Kurnakovite DA-NEAN (1965)
Inderite VALYASHKO & WLASSOWA (1969)	Kurnakovite CHRIST *et al.* (1967)
	Kurnakovite VALYASHKO & WLASSOWA (1969)
*Synthetic**	*Synthetic**
Inderite FEIGELSON *et al.* (1939)	'Inderite' HEINRICH (1946)
Inderite NIKOLAEV & CHELISHCHEVA (1940)	Kurnakovite SPIRYAGINA (1949)
Inderite D'ANS & BEHRENDT (1957)	

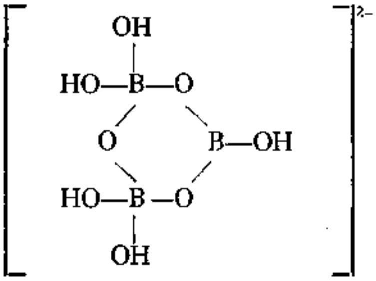
* Incorrect names are given in single quatation marks.

Kurnakovite is the most common mineral in the borate deposits of Sarıkaya after *borax* and *ulexite.* It is quite frequent in the drills K-4, K-10 and S-2, and less abundant in K-5, K-6 and K-7. It is also quite common in the excavated cover and in front of galleries 1, 5 and 8 of Turkish Borax Mining Company (see Baysal, 1972a, plate 1 and 2).

Kurnakovite is found in general on the top and on the sides of the deposits. Distribution of the mineral is not uniform and it is found focally in the clays, especially in the blue-green clays on top of the deposits. Frequently *ulexile, inderite* and *tunellite* and less frequently *borax* are found with *kttrnakavite.*

Mineralogical investigation

Pennington and Petch (1960, 1962) and Petch *et al.* (1962) have studied the crystal structure of *kurnakovite* (triclinic) and *inderite* (monoclinic). These two minerals are dimorph of 2MgO. $3B_2O_3.15H_2O$. These authors have determined that *kurnakovite* and *inderite* contain two BO_4-tetrahedral and one BO_3-triangle. According to Rumanova and Ashirov (1964) and Da-Nean (1965) *kurnakovite* and *inderite* have $[B_3O_3(OH)_5]^{-2}$ polyanions in their structures. Thus these authors agree with the first proposal of Christ (1960). It is established, therefore, that the structures of *kurnakovite* and *inderite* contain the essential inyoite-polyanion shown below.



Kurnakovite occurs in the clays of Sarıkaya borate deposits as idiomorph single crystals of crystal groups. Some single crystals reach 10-15 cm in size. The most prominent faces of the crystals are (010), (100), (001), (110) and (111), and the habit of the crystal are thick prisms or plates parallel with (010). Aggregates of thin prismatic *kurnakovite* crystals are also locally found. In these aggregates are clay minerals and needles and thin rods of ulexite. The cleavage of kurnakovite is good and parallel to (010) and (110). The angle between these faces is approximately 70°. Single crystals are often colorless or light gray, transparent and they have glassy luster. The aggregates on the other hand are turbid due to the presence of clay minerals. Specific gravity of *kurnakovite* is 1.862, and the hardness is approximately 3.

Kurnakovite is biaxial negative and its 2V is about 60°. Its refractive indices have been determined under the Na-lamp with the use of special immersion liquids and Abbe-refractometer, and they were found to be:

$n_x = 1.490 \pm 0.002$

$n_y = 1.510 \pm 0.002$

$n_z = 1.524 \pm 0.002$

Chemical composition

Table 2 lists the results of chemical analyses of two transparent, pure and colorless kurnakovite samples which were also checked by X-ray diffraction analyses.

It is seen from Table 2 that the results of chemical analyses of kurnakovite are in agreement with its theoretical chemical composition but different from the results of the first original sample of Godlevsky (1940). His sample contains a higher percentage of MgO and B_2O_3 but a smaller percentage of H_2O. Indeed Godlevsky (1940) had formulated *kurnakovite* as $2MgO.3B_2O_3.13H_2O$. As it was pointed out by Schaller and Mrose (1960) there might have been mistakes in the first chemical analyses and therefore it is possible that *kurnakovite* was at first improperly formulated.

Table - 2

Chemical composition of kurnakovite, inderite and inderborite

	Kurnakovite			*Inderite*			*Inderborite*	
Analysis no.	1	2	*Theor. compos.*	1	2	*Theor. compos.*	1	*Theor. compos.*
MgO	14.52	14.46	14.41	14.36	14.28	14.41	8.60	8.01
CaO	—	—	—	—	—	—	10.62	11.14
B_2O_3	37.45	37.28	37.32	37.42	37.16	37.32	41.34	41.49
H_2O	47.96	48.14	48.27	48.38	48.05	48.27	39.61	39.36
Insoluble in acid ...	—	—	—	—	0.65	—	—	—
Total :	99.93	99.88	100.00	100.16	100.14	100.00	100.17	100.00

X-ray diffraction analysis

X-ray diffraction analyses were made of nearly 30 samples taken from different locations in the deposits. The machine used was a General Electric 'X-Ray Diffractometer 700'. Same results were obtained from all the samples. One of the diagrams with the calculated d-spaces is given in Figure 1 in order to compare with *inderite* and *inderborite.* It is clear from Figure 1 that the X-ray diffraction diagrams of these three minerals are completely different.

The author has found no literature about the X-ray diffraction analyses of *kurnakovite,* other than that of Heinrich (1946). As a result, comparisons were made only with Heinrich (1946). The spaces of the *kurnakovite* samples from Sarıkaya are in general accordance with those given by Heinrich (1946), (ASTM 8-160). In addition there are several peaks in the diagram and these are indicated with question marks. Because there is a lack of literature and lack of data to compare with, it is impossible to draw any concrete conclusions at this stage whether these extra peaks are special to *kurnakovite.*

Alterations

No changes have been observed in the *kurnakovite* samples. The crystals that are generally fresh, preserved their original form. Observations prove that Mg-borates and especially *kurnakovite* are the most stable borates.

Inderborite crystals seen with *kurnakovite* are pseudomorphs after the latter. This point will be stressed later. Structural connections between these two minerals also seem to indicate this origin.

INDERITE

Structure formula : $Mg[B_3O_3(OH)_5].5H_2O$

Oxide formula : $2MgO.3B_2O_3.15H_2O$

Occurrence

As it was mentioned earlier, *inderite* was first discovered in Inder borate deposits of West Kazakhistan by Boldyreva (1937) and Godlevsky (1937). The same mineral was later found in Kramer deposits of California by Frondel and Morgan (1956b) and it was called *'lesserite'.* It is cited in the literature that *inderite* was found also in Argentine, but no definite information is given about the locality or the properties of the mineral (Muessig, 1959). Like *kurnakovite, inderite* was first discovered in Turkey by the author in the borate deposits of Sarıkaya.

Inderite is found with kurnakovite in the blue-green clays (top) and in the clay-marl layers. Its distrubition is similar to that of *kurnakovite* but it is much more rare than *kurnakovite.* It is mostly found in the drills K-10 and S-2, in the excavated zone and in front of the gallery no. 5 of Turkish Borax Mining Company (see Baysal, 1*972a,* plate 1).

Mineralogical investigation

Studies of the crystal structure of *inderite* have shown that it too contains $[B_3O_3]^{-2}$ inyoite-polyanion (Rumanova & Ashirov, 1964). The difference is that *kurnakovite* is triclinic, whereas *inderite* is monoclinic.

Inderite crystals are in the form of thin rods and needles. Their habit is prismatic. These crystals occur in the clays and in *kurnakovite* crystals as radial and spherulitic aggregates which cut the clays and the *kurnakovite* crystals. *Inderite* crystals are 1-2 cm long and 1-2 mm wide. Larger crystals have also been found. *Inderite* has a good cleavage parallel with {110}, but this cleavage is not so good as that of *kurnakovite.* Polysynthetic twinning is often seen in thin section. The crystals are colorless, transparent and have a glassy luster. *Inderite* crystals in clays appear gray and turbid because they contain almost always small amounts of clay. The clay minerals usually fill the cleavage openings. Macroscopically *kurnakovite* and *inderite* are difficult to distinguish. The specific gravity and the hardness of *inderite* are 1.780 and 2.5 respectively. *Inderite* is biaxial positive with a 2V of 40-45°. Its refractive indices under the sodium light are:

$n_x = 1.486 \pm 0.002$

$n_y = 1.490 \pm 0.002$

$n_x = 1.506 \pm 0.002$

Chemical composition

Chemical analyses were made of two samples which were also checked with optical and diffraction methods. The results are given in Table 2.

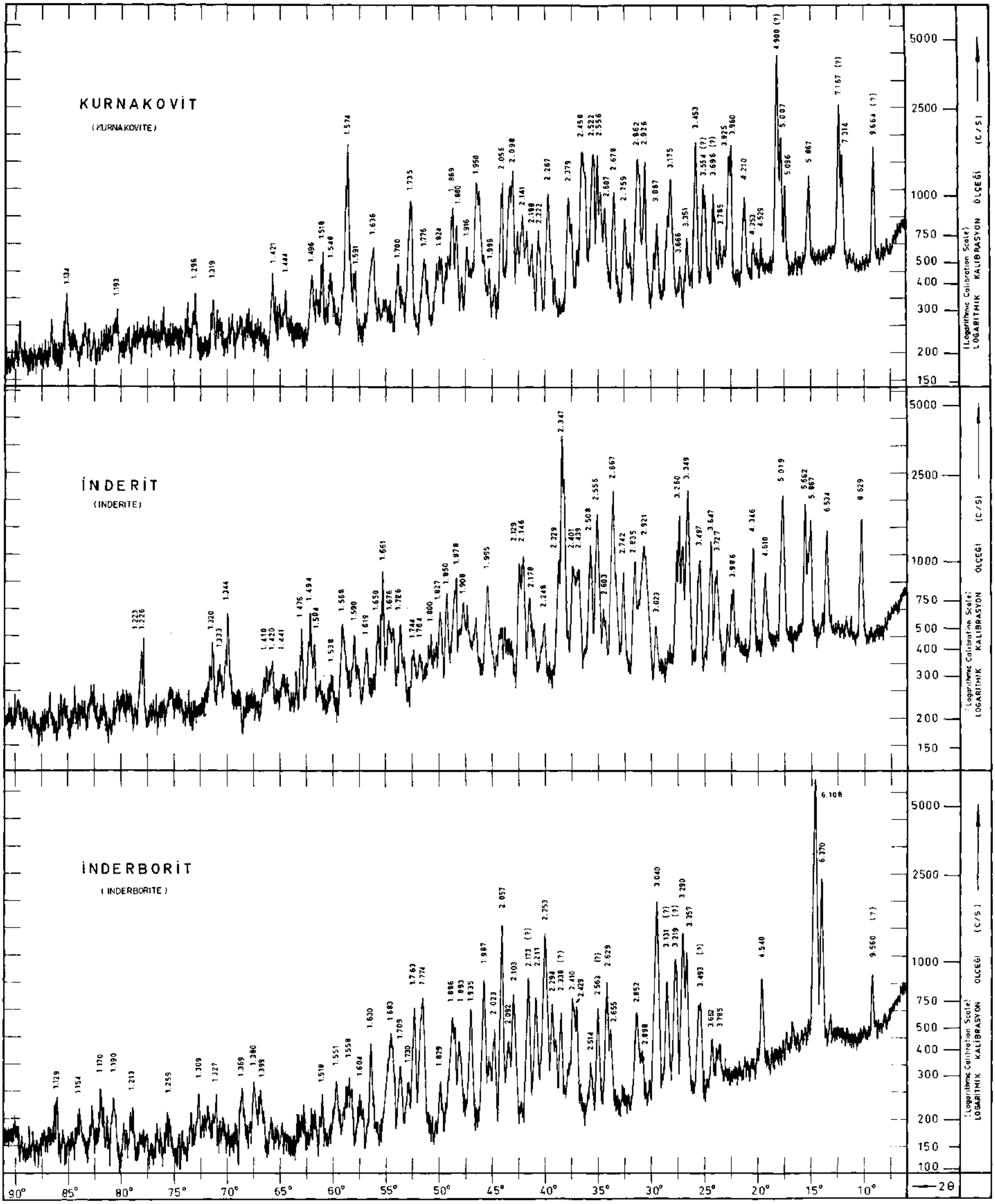
The first sample analyzed is colorless, transparent and in the form of large crystals. The second is gray and thin prismatic crystals. It was picked out from the clays. The clay portion of this sample is not dissolved in acid.

X-ray diffraction analysis

Powder diffraction analyses were made of several *inderite* samples. One of the diffraction diagrams with the calculated d-spacings is given in Figure 1. The d-spaces are in accordance with those given by Frondel and Morgan *(1956b)* (ASTM 11-583). The mineral which is listed as 'lesserite' in ASTM 11-583 should be called '*inderite'.*

Alterations

Inderite crystals taken from Sarıkaya borate deposits are fresh and not much altered. Some clay inclusions are seen in the cleavage and polysynthetic twinning planes of crystals and crystal aggregates. Solutions coming from these planes become mixed with clay and the *inderite* crystals and form new features which look like fish skeletons. Dolomite and unidentifiable pseudomorphs form as well. These pseudomorphs are thought to be hydromagnesite.



KURNAKOVİT
(KURNAKOVITE)
1.134
1.193
1.296
1.319
1.421
1.444
1.496
1.518
1.540
1.574
1.591
1.636
1.700
1.735
1.776
1.824
1.869
1.880
1.916
1.950
1.999
2.056
2.098
2.141
2.198
2.222
2.267
2.379
2.458
2.522
2.556
2.607
2.678
2.759
2.862
2.926
3.087
3.175
3.351
3.453
3.554 (?)
3.666
3.696 (?)
3.785
3.925
3.960
4.210
4.353
4.529
4.900 (?)
5.007
5.096
5.867
7.167 (?)
7.314
9.664 (?)
İNDERİT
(INDERITE)
1.223
1.226
1.320
1.333
1.344
1.410
1.420
1.441
1.475
1.494
1.504
1.538
1.568
1.590
1.619
1.650
1.661
1.676
1.726
1.744
1.764
1.800
1.827
1.850
1.878
1.900
1.995
2.129
2.146
2.178
2.248
2.329
2.347
2.401
2.439
2.508
2.556
2.603
2.667
2.742
2.835
2.921
3.023
3.250
3.349
3.497
3.647
3.727
3.986
4.346
4.610
5.019
5.662
5.867
6.534
8.629
İNDERBORİT
(INDERBORITE)
1.129
1.154
1.170
1.190
1.213
1.259
1.309
1.327
1.369
1.380
1.399
1.518
1.551
1.558
1.604
1.630
1.683
1.709
1.730
1.763
1.774
1.829
1.886
1.893
1.935
1.987
2.023
2.057
2.092
2.103
2.173 (?)
2.211
2.253
2.294
2.338 (?)
2.410
2.429
2.514
2.563 (?)
2.629
2.655
2.852
2.898
3.040
3.131 (?)
3.219 (?)
3.290
3.357
3.493 (?)
3.662
3.785
4.540
6.108
6.370
9.560 (?)
5000
2500
1000
750
500
400
300
200
150
100
(Logarithmic Calibration Scale)
LOGARİTMİK KALİBRASYON ÖLÇEĞİ (C/S)
90°
85°
80°
75°
70°
65°
60°
55°
50°
45°
40°
35°
30°
25°
20°
15°
10°
2θ

INDERBORITE

Structure formula : $CaMg[B_3O_3(OH)_5]. 6H_2O$
Oxide formula : $CaO. MgO. 3B_2O_3.11H_2O$

Occurrence

Inderborite was first reported by Gorshkov (1941), Ikornikova and Godlevsky (1941) from Inder borate deposits in West Kazakhistan. Ikornikova and Godlevsky (1941) named this mineral *metahydroboracite* but in the literature *inderborite* is preferred. The latter was used by Gorshkov. The author has found no other localities of *inderborite* in the literature. It was first observed in Turkey by the author in Sarıkaya borate deposits.

Inderborite was rare and local in the deposits of Sarıkaya. It was not encountered either in the drill cores of M.T.A. or Etibank but was scarce in the ore debris in front of the gallery *5* and Kuşkaya gallery of Turkish Borax Mining Company (see Baysal, 1972a, plate 1). In these ore accumulations *kurnakovite, ulexite,* some *inderite,* and *borax* were also present.

Mineralogical description

Inderborite too, as kurnakovite and inderite, contains $[B_3O_3(OH)_5]^{-2}$ polyanions. Magnesium forms independent octahedra in the structure of inderborite. In addition, calcium polyhedra form sheets which go through the polyanions and therefore form tight bonds (Kurkutova *et al.,* 1965). Valyashko and Wlassowa (1969) think that this structure *of inderborite* is the reason why inderborite can dissolve easily and break into Mg $(OH)_2$.

Inderborite from the ore accumulations was found intergrown with *kurnakovite* and *ulexite,* especially with the former. In several samples consisting of thick prismatic *kurnakovite* crystals *inderborite* was found, which had similar crystals growth with *kurnakovite.* These two minerals were intergrown very tightly and there was no definite boundary between them.

Inderborite is in the form of thick prismatic crystals which can reach a few centimeters in length. {100} cleavage is good. Generally the crystals are white, semitransparent and they have glassy and weak pearly luster on the cleavage faces. Colorless and transparent crystals are also found. The specific gravity and the hardness of inderborite are 1.930 and 2.5 respectively.

Inderborite is monoclinic and biaxial negative with a 2V of 80-85°. Its refractive indices under the Na-light are:

$n_x = 1.490 \pm 0.002$
$n_y = 1.516 \pm 0.002$
$n_z = 1.536 \pm 0.002$

Chemical composition

Table 2 shows the chemical composition of a pure *inderborite* crystal. It is seen that the chemical composition of the analyzed sample differs from that of inderborite, in that the CaO content is lower in the former, and MgO and H_2O content is higher. This probably results from a partial subtitution in the lattice of some Ca atoms by Mg atoms.

X-ray diffraction analysis

X-ray powder diffraction analyses of *inderborite* were made in addition to chemical and microscopic studies. Figure 1 shows the diffraction diagram and the calculated d-spaces.

Most of the d-spaces of the analyzed *inderborite* sample, especially those that are characteristic for *inderborite,* accord with those belonging to the sample from Inder, Kazakhistan, and listed in ASTM (12-70). The differences are in acceptable limits. In the diagram there are some peaks which were indicated with question marks. Some of these peaks coincide with the peaks of *kurnakovite.* The author thinks that this is also caused by the Mg atoms, in the lattice. Had there been *kurnakovite* with *inderborite,* the characteristic 7.314 (7.167), 5.000 (4.910) peaks *of kurnakovite* would also have been obtained. Detailed study should be made of this point in the line of crystal structure. This will be made in the future.

Alterations

Cryptocrystalline calcite occurs locally in *inderborite* crystals, especially in the cleavage planes. It is not definitely known whether these are pseudomorphs of *inderborite* or they formed from solutions leaking in the cleavage planes. Both possibilities seem acceptable, according to the author.

Thin *kurnakovite* crystals which occur between *inderborite* crystals are not pseudomorphs but rather remnants of *kurnakovite* crystals. This point will be stressed later when the genetic relations between *kurnakovite* and *inderborite* are studied.

ORIGIN OF MAGNESIUM-BORATES

As it was mentioned earlier, Sarıkaya borate deposits formed in the Neogene lakes from the boron exhalations, coming from faults, and volcanic mud and ash. X-ray diffraction and chemical analyses showed that magnesium is not abundant in the lower limestones and in the top of upper limestones. On the contrary magnesium is very abundant in the borate series, argillaceous rocks and the tuffaceous sandstone series (Baysal, 1972a). It is clear from this fact that magnesium is of volcanic origin in the Sarıkaya borate deposits. In other words the volcanic exhalations which formed the deposits contained magnesium as well as boric acid and sodium. In addition, magnesium concentration in the lakes increased from time to time due to the hydrolization of pyroclastic material. It is evident that calcium came to the lakes from other sources. The thick limestones formed before and after the volcanic events.

It is known that the primary borate minerals that form under surface conditions are the most hydrous members of their series (Muessig, 1959; Christ *et al.,* 1967; Özpeker, 1969; Baysal 1972a). Therefore *kurnakovite* and *inderite* formed as primary minerals in Sarıkaya borate deposits. It is seen in Figure 2 that the deposition of these two minerals is controlled by the proportion $[Ca^{++}]/[Mg^{++}]^1$ and $[H_2O]$. The author thinks that the concentration of Ca^{++} and Mg^{++} in the lakes increased in the late stages of deposition of borax. When the Ca^{++}/Mg^{++} reached the limit for the deposition of *kurnakovite* and *inderite,* these minerals formed and therefore the lake water was impoverished in Mg^{++}. This is proved by the fact that *kurnakovite* and *inderite* are generally found in the clays, on top of the deposits. In addition, pyroclastic material rich in Mg played a role in the deposition of these minerals. Chemical analyses showed that the blue and gray clays in the upper portion of the deposits are rich in Mg (Baysal, 1972a). When *kurnakovite, inderite* and locally *ulexite* formed in the lower parts of the clays, diagenetic dolomitization took place by Mg-hydration in the upper parts. Considering these factors it seems that the magnesium which caused the deposition of *kurnakovite* and *inderite,* must have at least in part come from the hydrolization of late pyroclastic material.

Observations indicate that *inderite* and *kurnakovite* were deposited together. Common growth of these polymorphs was undoubtedly controlled by thermodynamic and geochemical conditions, but no definite conclusions can be made at this moment, because the genetic and stability relations between these polymorphs are not known yet. In some deposits, for example Death Valley (California) and Inder (Russia) *kurnakovite* and *inderite* are intergrown with *hydroboracile.* Here prismatic *inderite* crystals pierce through *kurnakovite* (Christ *et al.*, 1967). In Kramer (California), however, *inderite* and *kurnakovite* are individual minerals.

There is little inderborite in the deposits which formed from Mg-borates and especially from *kurnakovite* as a pseudomorph of the latter. Because, as it was mentioned above, *kurnakovite* daggers were found in *inderborite,* geochemically it is possible that *inderborite* may form from *inderite* but no structural connection between *inderite* and *inderborite* has been determined.

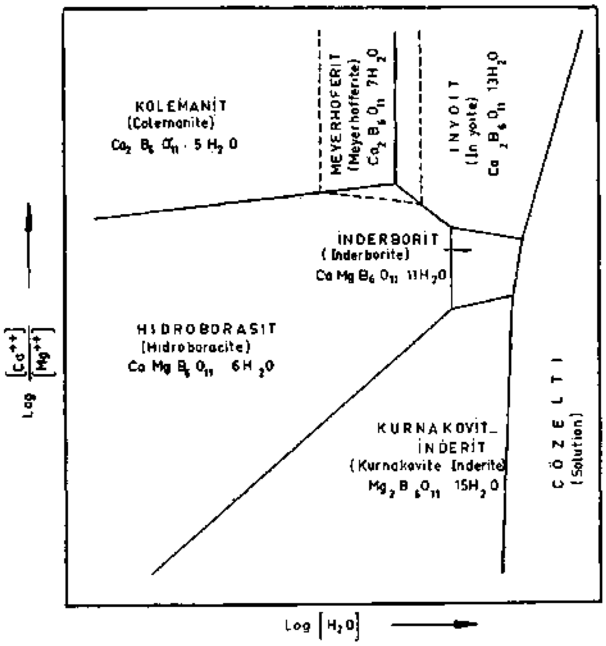


Fig. 2 - Schematic plot of the phase relations in the system $2CaO.3B_2O_3.5H_2O - 2MgO.3B_2O_3.7H_2O - H_2O$.

The solids are in equilibrium with saturated solution; brackets denote activities; the dashed lines enclose metastable fields. System is closed with respect to boron and open with respect to the cations and H_2O. As drawn, 1 unit along the Log $[H_2O]$-axis is equal to 10 units along the Log $[Ca^{++}]/[Mg^{++}]$-axis. A scale of this kind is in accordance with the fact, that Log $[H_2O]$ can vary only over a fraction of the range of Log $([Ca^{++}]/[Mg^{++}])$.

(From C.L. Christ; A.H. Truesdell & R.C. Erd, 1967).

Observations in the field as well as experiments and thermodynamic, geochemical principles indicate that the activity of capillary water fell after the deposition and burial of sediments because of the rising temperature and pressure. As a result highly primary borates became dehydrated and formed the less hydrous borates of their series. If there is a change in the chemical composition of capillary solution along with a change in the temperature and pressure, hydrous borates chemically different from primary borates can form. Although there was not much change in the temperature and pressure in the upper zones of Sarıkaya deposits, circulation in the composition of capillary water and the subterranean waters gave rise to a higher concentration of calcium. Therefore *kurnakovite* which formed as a primary mineral lost its stability after the burial of deposits and turned locally into *inderborite.* This chemical reaction is formulated below and is also seen in Figure 2.

$$\underbrace{Mg_2B_6O_{11}.15H_2O}_{\text{Kurnakovite}} + Ca^{++} \rightleftarrows \underbrace{CaMgB_6O_{11}.11H_2O}_{\text{Inderborite}} + Mg^{++} + 4H_2O$$

REFERENCES

BAYSAL, O. (1968): About the mineralization of Kırka-Sarıkaya-Bor salt drill cores. *M.T.A. Miner. Rep.* no. 5757, 5758, 5771, 5772, 5777, Ankara (unpublished).

———(1969): About the mineralization of Kırka-Sarıkaya-Bor salt drill cores. *M.T.A. Miner. Rep.* no. 5823, 5824, 5828, 5839, 5883, Ankara (unpublished).

———(1970): About the mineralization of Kırka-Sarıkaya-Bor salt drill cores. *M.T.A. Miner. Rep.* no. 1579, 1681, Ankara (unpublished).

———(1972a): A mineralogical study and genesis of Sarıkaya (Kırka) borate deposits. *Hacettepe University,* Ankara (in press).

——(1972b): Tunellite, a new hydrous strontium borate from the Sarıkaya borate deposits in Turkey. *M.T.A. Bull.* no. 79, Ankara.

BOLDYREVA, A. (1937): Investigation of inderite and of the including rock. *Mem. Soc. Russe Min.,* 66, no. 4, 2. ser. pp. 651-672.

CHRIST, C.L.; TRUESDELL, A.H. & ERD, R.C. (1967): Borate mineral assemblages in the system Na_2O-CaO-MgO-B_2O_3-H_2O. *Geochim. et Cosmochim. Acta,* vol. 31 pp. 313-339.

DA-NEAN YEH (1965): The structure of kurnakovite. *Scientia Sinica,* XIV, pp. 1086-1089 (cit. *in* CHRIST *et al.,* 1967).

D'ANS, J. & BEHRENDT, K.H. (1957): Über die Existensbedingungen einiger Mg-borate. *Kali und Salz,* 2, pp. 121-137.

FEIGELSON, J.B.; GRUSHVITSKY, V.E. & KOROBOCHKINA, W.V. (1939): Synthesis of inderite. *Compt. Rend. Doklady, Ac. Sci. USSR, 22,* pp. 242-243.

FRONDEL, C. & MORGAN, V. (1956a): Inderite and gerstleyite from the Kramer borate district, Kern County, California. *The Amer. Min.,* vol. 41, pp. 839-843.

———(1956b): Lesserite, a new borate mineral. *The Amer. Min.,* vol. 41. pp. 927-928.

GODLEVSKY, M.N. (1937): Mineralogical investigation on the Inder borate deposits. M*em. Soc. Russe de Mineralogie,* 66, Liefg. 2, pp. 315-344.

———(1940): Kurnakovite, a new borate. *Compt. Rend. Doklady Acad. Sci., USSR,* vol. 28, pp. 638-640.

GORSHKOV, G.S. (1941): A new mineral from the region of Lake Inder. *Compt. Rend. (Doklady) Acad. Sci., USSR,* vol. 33, pp. 254-256.

HEINRICH, E.W. (1946): A second discovery of inderite. *The Amer. Min.,* vol. 31, p. 71.

IKORNIKOVA, M.V. & GODLEVSKY, M.N. (1941): The new borate: metahydroboracite. *Compt. Rend, (Doklady) Acad. Sci. USSR,* vol. 33, pp. 257-258.

KURKUTOVA, A.G.; RUMANOVA, I.M. & BELOV, N.V. (1965): cit. *in* VALYASHKO, M.G. & WLASSOWA, E.W. (1969).

MUESSIG, S. (1959): Primary borates in playa deposits: minerals of high hydration. *Econ. Geol.,* 54, pp. 495-501.

———& ALLEN, R.D. (1957): Ezcurrite ($2Na_2O$. $5B_2O3.7H_2O$), a new sodium borate from Argentina, occurrence, mineralogy, and associated minerals. *Econ. Geol.,* 52, pp. 426-437.

NIKOLAEV, A.V. & CHELISHCHEVA, A.G. (1940): The 25° isoterm of the system: CaO + B_2O_3 + H_2O and MgO + B_2O_3 + H_2O. *Compt. Rend. Acad. Sci. USSR,* 28, pp. 127-130.

PENNINGTON, K.S. & PETCH, H.E. (1960): Nuclear magnetic resonance spectrum of B11 in inderite. J. *Chem. Phys.,* 33, pp. 329-334.

———(1962): Nuclear magnetic resonance spectrum of B_{11} in lesserite. *J. Chem. Phys.,* 36, pp. 2151-2155.

PETCH, H. E.; PENNINGTON, K.S. & CUTHBERT, J.D. (1962): On Christ's postulated boronoxygen polyions in some hydrated borates of unknown crystal structure. *The Amer. Min.,* vol. 47, pp. 401-404.

RUMANOVA, I.M. & ASHIROV, A. (1964): The determination of the crystal structure of inderite. *Sov. Phys. Cryst.,* 8, pp. 414-428.

SCHALLER, W.T. & MROSE, M.E. (1960): The naming of the hydrous magnesium borate minerals from Boron, California. *The Amer. Min.,* vol. 45, pp. 732-734.

SPIRYAGINA, A.I. (1949): Condition of formation of kurnakovite. *Doklady Acad. Nauk. USSR,* 68, p. 909-911.

ÖZPEKER, I. (1969): Batı Anadolu borat yataklarının mukayeseli jenetik etüdü. (A comparative genetic study of borate deposits of Western Anatolia). *Ak Printing House* (Doctorate thesis), İstanbul, 116 p.

VALYASHKO, M.G. & WLASSOWA, E.W. (1969): IR-Absorptionsspektren von Boraten und borhaltigen waessrigen Losungen. *Jenaer Rundschau,* Heft 1, S. 3-11.